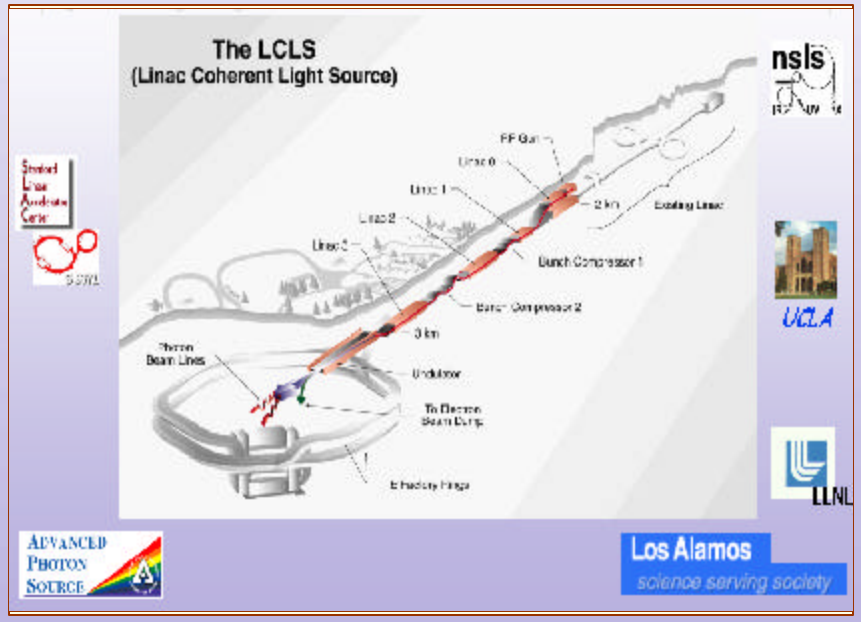
X-Ray Free Electron Lasers - Progress Toward Their Development in the U.S. and Abroad

Keith Hodgson, SSRL Director

August 5, 2002



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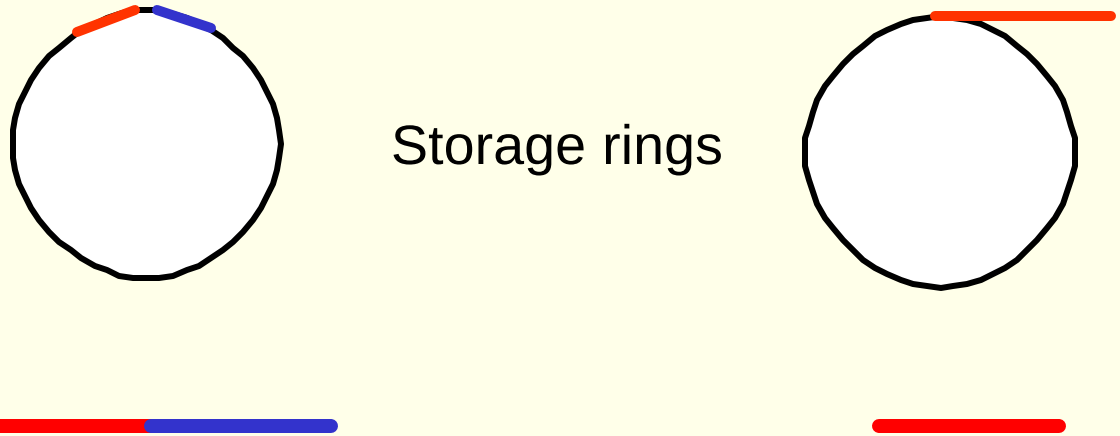
From Storage Rings to Linacs - Leveraging the Investment by HEP in Accelerator Physics and Construction of Frontier Accelerators

HEP **SR**



Storage rings

Single pass linear colliders

Single pass linacs

Free electron lasers (FELs)
Energy recovery linacs (ERLs)

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Brightness and Pulse Length in Electron-based X-ray Generation

- *X-ray brightness determined by electron beam brightness*
- *X-ray pulse length determined by electron beam pulse length*

Storage ring ("conventional synchrotron radiation")
Emittance and bunch length are result of an equilibrium
Typical numbers: 2 nm rad, 50 psec

Linac (source for X-ray FEL or ERLs)
Normalized emittance is determined by electron gun
Bunch length is determined by electron compression
Typical numbers: 0.03 nm rad, 100 fs or shorter

Linac beam can be much brighter and pulses much shorter! – at cost of "jitter" – and provides necessary characteristics for ERLs and X-ray FEL generation

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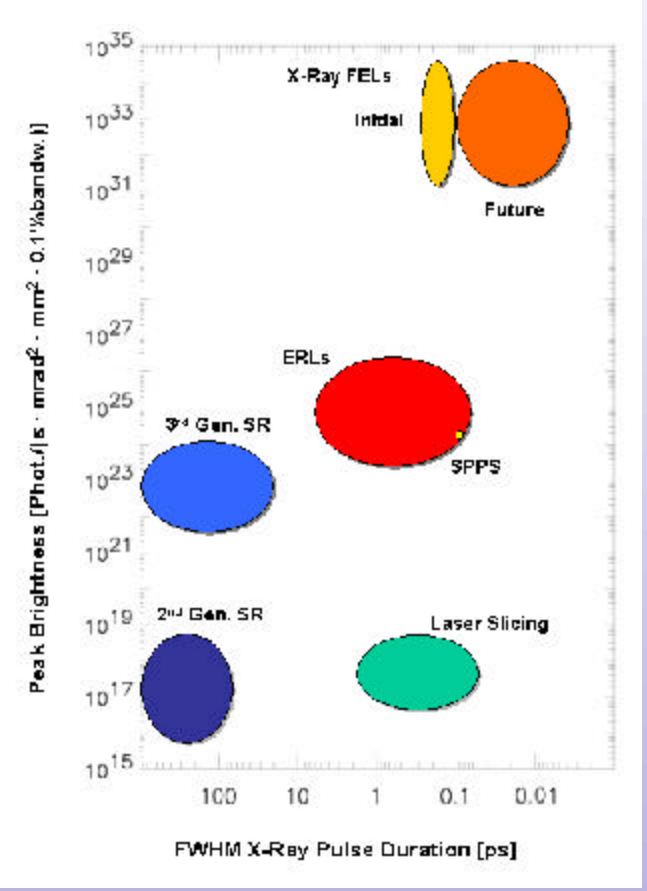
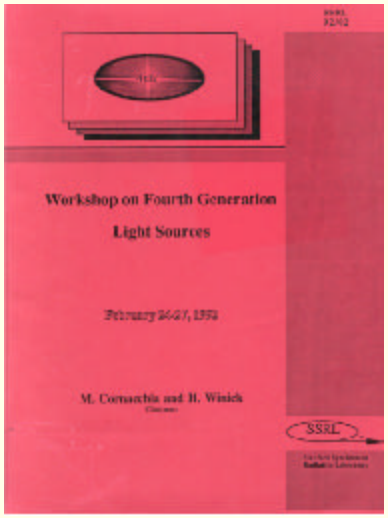
Storage Ring vs. Linac-based Sources

- *Different sources matched to different experimental studies*
- *XFELs can achieve extreme peak brightness and ultrashort pulses*
- *ERLs have high repetition rates and can serve many beam lines*
- *ERLs can be optimized for short pulses or high brightness - but very challenging to do both*
- *XFELs can also serve multiple beam lines but require multiple long undulators*

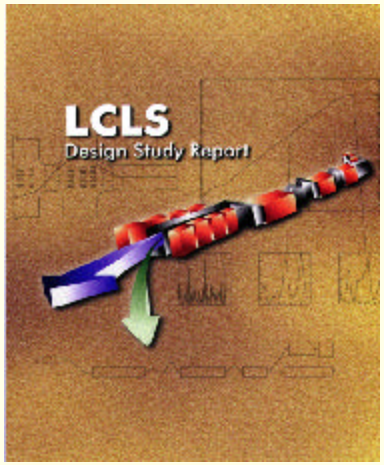


XFEL and LCLS History - Project Evolution - 1992 - 1999



- *February, 1992 - Workshop Proposal for a h? > 300 eV FEL Based on the SLAC Linac by C. Pellegrini, UCLA*

- *February, 1992 - LCLS Technical Design Group formed by H. Winick*



- *August, 1996 – The LCLS Design Study Group, under the leadership of Max Cornacchia, begins work on the first LCLS Design Report*

- *December 1998 – The first edition of the LCLS Design Study Report is published (Tesla XFEL Design Report appeared 2001)*

Scientific and Programmatic Recommendations - U.S.

- ***1994,*** *National Research Council Study*
  "Free Electron Lasers and Other Advanced Sources of Light, Scientific Research Opportunities"
  concluded that FELs were not competitive with conventional lasers for scientific applications except in the X-ray region.
- ***1997,*** *Birgeneau-Shen BESAC Subpanel Report*
  "DOE Synchrotron Radiation Sources and Science"
  recommended funding an R&D program in next-generation light sources and convening another BESAC panel to focus on this topic.

- ***1999,*** *Leone BESAC Subpanel Report*
  "Novel, Coherent Light Sources"
  concluded: "Given currently available knowledge and limited funding resources, the hard X-ray region (8-20 keV or higher) is identified as the most exciting potential area for innovative science. DOE should pursue the development of coherent light source technology in the hard X-ray region as a priority. This technology will most likely take the form of a linac-based free electron laser using self-amplified stimulated emission or some form of seeded stimulated emission…"

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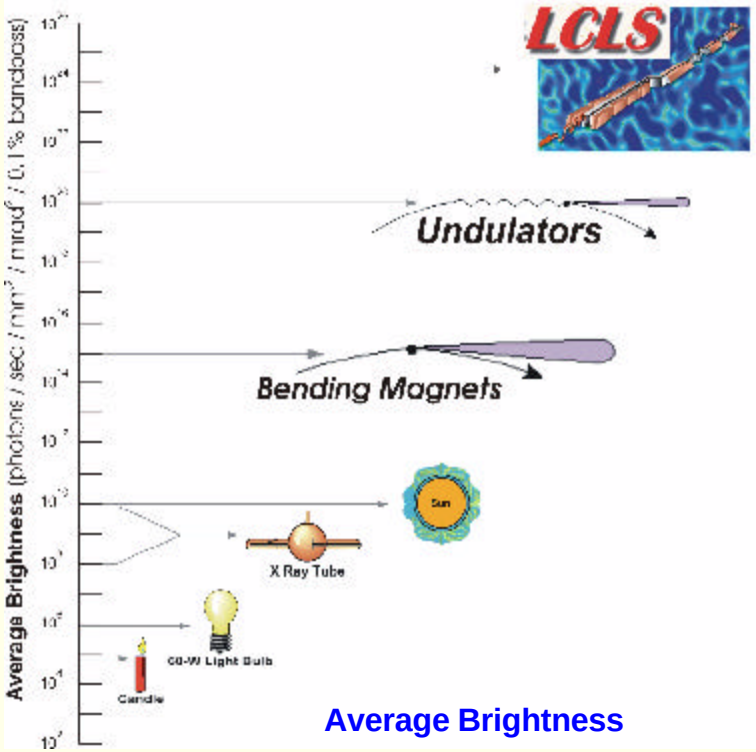
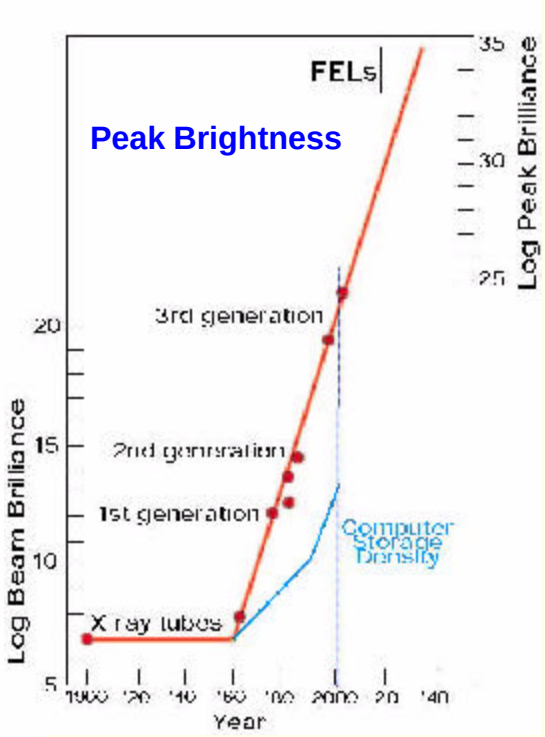
XFELs Like LCLS - Properties Enable Unique New Science

How bright are different light sources ?



Average Brightness



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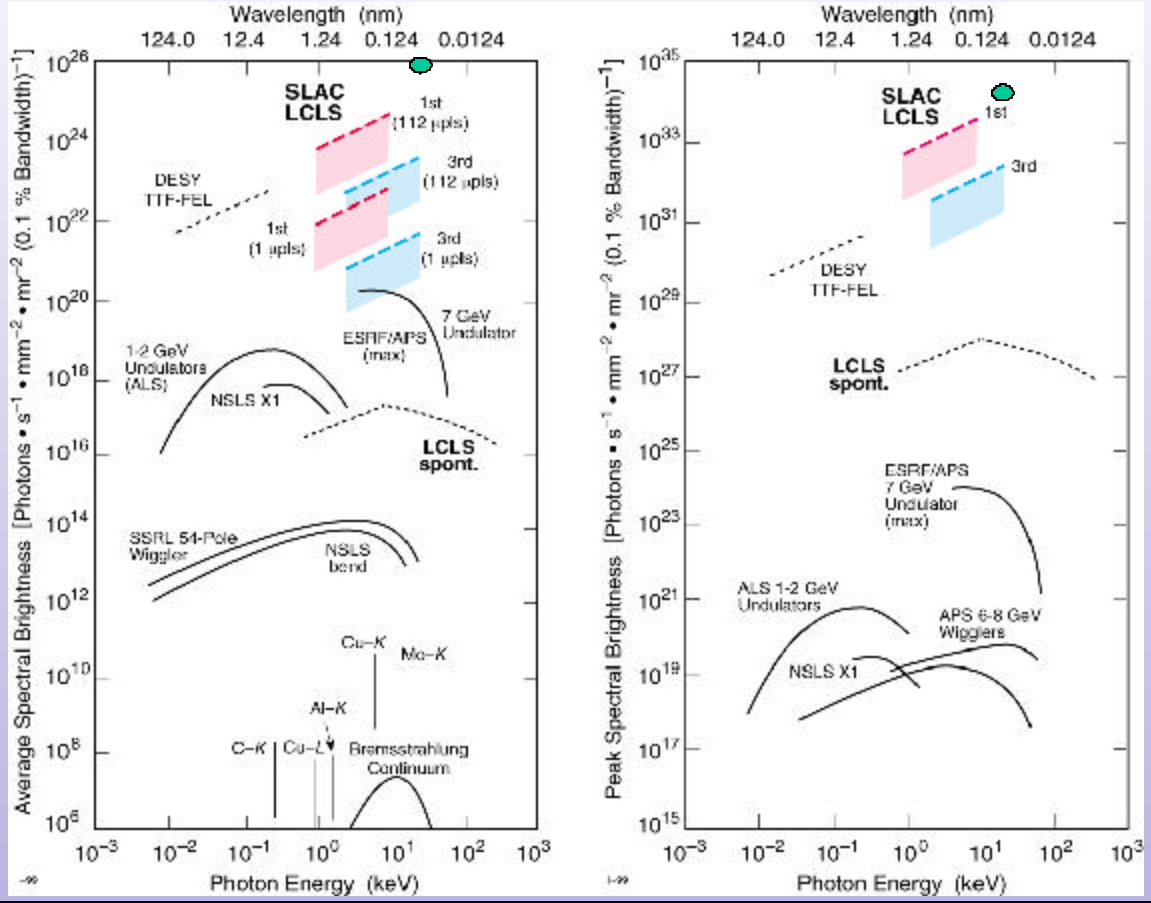
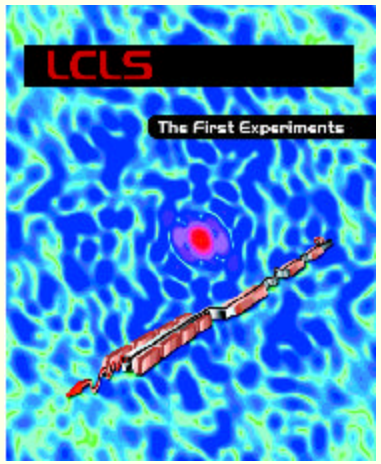
LCLS at SLAC – a Multilaboratory Collaboration with Stewardship by DOE-BES to Build an X-ray FEL with Operation Beginning in 2008

Peak and time averaged brightness of the LCLS and other facilities operating or under construction

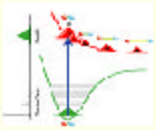
- **~ TESLA XFEL Performance**



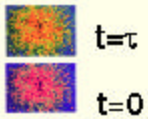
LCLS Science Program - Opportunities for Discovery



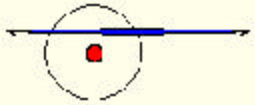
Program developed by international team of ~45 scientists working with accelerator and laser physics communities



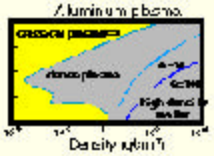
Femtochemistry — Dan Imre, BNL



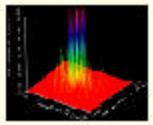
Nanoscale Dynamics in Condensed matter — Brian Stephenson, APS



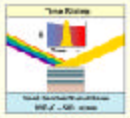
Atomic Physics — Phil Bucksbaum, Bucksbaum, Univ. of Michigan



Plasma and Warm Dense Matter — Richard Lee, LLNL



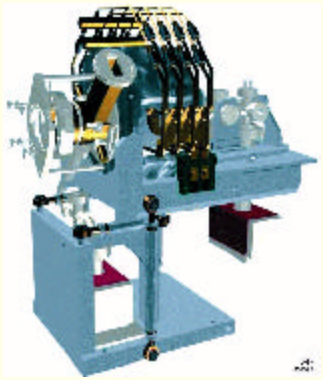
Structural Studies on Single Particles and Biomolecules — Janos Hajdu, Uppsala Univ.



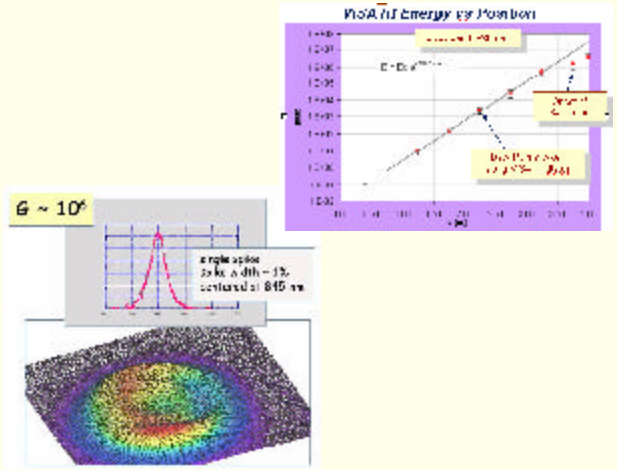
X-ray Laser Physics — LCLS Team

LCLS Program - the R&D Phase Includes Engaging Accelerator Physics Questions

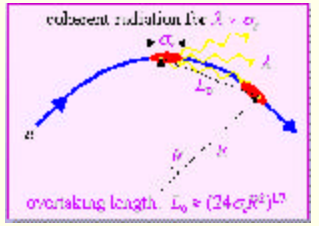
- *Collaborating Laboratories (SLAC/SSRL, ANL/APS, LLNL, BNL/NSLS, ANL, and UCLA) responsible for R&D effort addressing issues on key areas including:*



Photocathode Gun Development



SASE Physics - Experiments and Simulations



Understanding/mitigating Effects of Coherent Synchrotron Radiation

Undulator Design and Prototype

LCLS History and Project Evolution - Recent Events

- *April, 2001* — *John Galayda joins SSRL/SLAC as Project Director*
- *June, 2001* — *CD0 (Statement of Mission Need) Approved by DOE*
- *February, 2002* — *President's FY2003 Budget Includes $6M LCLS PED Funding*
- *February, 2002* — *LCLS Science Advisory Committee Meets and Formulates Strategy for Framework of Experimental Program Development*
- *April, 2002* — *Validation by DOE Lehman Project Review (4/23-25) with at TPC of $268M, completed in FY2008*
- *Sept., 2002* — *CD1 SC Review*

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World Perspective - Toward XFELs

- ***Germany*** *– Pursuing now a separated X-ray FEL and linear collider*
  - *XFEL facility that could come on-line late this decade proposed to include*

    5 SASE FEL beam lines and 5 spontaneous radiation sources

    €274M for accelerator and €399M for photon component

    €673M (or €744M including R&D) for an independent XFEL
  - *Tesla FEL project given high ranking in recent report by the German Science Council (in same class with HEP linear collider)*
    - *Calls for Technical Design Report – faster-track, scaled-down XFEL with 5 undulators and a 20 GeV linac*
    - See *http://WWW.WISSENSCHAFTSRAT.DE/presse/pm_2002.htm*
  - *TTF2 soft X-ray FEL expected to become operational in 2004 at 6 nm wavelength*
- ***Japan*** *- has significant effort funded at SPring-8 in FEL development of a soft X-ray FEL but with goal of a second phase to extend to the hard X-ray region. Performance coupled to a innovative and challenging design.*

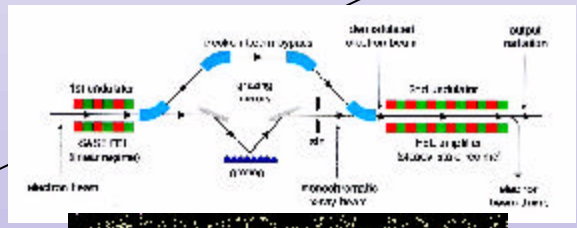
International R&D Collaborations 2002-2008

- Strong foundation for collaborations:
  - accelerator science & technology
  - X-ray instrumentation
  - X-ray science

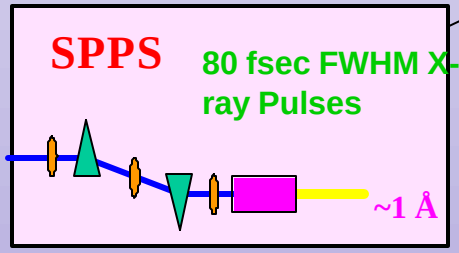
TESLA FEL

2008

2003-2007
Seeding, harmonic generation



2002-2006
Short pulse studies
Beam dynamics



- SLAC and DESY planning an international workshop to explore opportunities

Summary

- *XFELs (and LCLS in the U.S.) will be a source of unprecedented brightness and coherence, delivered in sub-picosecond X-ray pulses*
- *LCLS is the most rapid and cost effective path in the U.S. to realize an X-ray FEL synchrotron light facility*
- *It is based on technology and know-how available at the collaborating institutions and takes advantage of the availability of the SLAC Linac*
- *Builds on activities of DOE laboratories and universities in synchrotron R&D and in laser physics and accelerator physics and science*
- *R&D activities coordinate well with efforts in Europe and plans for future XFEL facility at DESY*
- *Will be an extraordinary new scientific tool continuing the DOE tradition of providing forefront research facilities to the scientific community*

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And at the End…

- *With thanks for the opportunity to visit with HEPAP today and share with you the vision for the future of DOE BER and for the development of an X-ray FEL!*